Rheological, viscoelastic and plastic properties of faecal sludge from VIP latrines

Septien Stringel, S.
Teba, L., Pocock, J., Velkushanova, K., Buckley, C.A.

Pollution Research Group, University of Kwa-Zulu Natal, Howard College, 4041 Durban
Motivation of the study

• VIP latrines widespread worldwide, particularly in the African context

• Faecal sludge an hazardous material

• Lack of data in literature about mechanical properties of faecal sludge

• Required for the design of pit emptying, mechanical handling and process equipment
Location of the study

30,000 VIP latrines
Methodology

Sampling

Diagram of a VIP latrine showing the layers from which the samples were selected in the front and back sections.

Rheometer:
- Static tests (flow)
- Dynamic tests (viscoelasticity)

Cone penetrometer:
- Liquid limit
- Plastic limit

Moisture and ash content analysis
Methodology

Alteration of moisture content
- Addition of water to increase moisture content
- Mixing with dried sludge to lower moisture content

Rheometer:
- Static tests (flow)
- Dynamic tests (viscoelasticity)
Modelling

Power Law

\[ \tau = K \cdot \dot{\gamma}^n \]

\[ K = a \cdot MC^b \]

\[ n = c \cdot MC^d \]

\( \tau \): shear stress [Pa]
\( \dot{\gamma} \): shear rate [s\(^{-1}\)]
\( n \): flow behaviour index [-]
\( K \): consistency coefficient

Application for pit emptying

\[ \Delta P = \frac{4 \cdot \rho \cdot f \cdot L \cdot V^2}{2 \cdot D} \]

\[ f = \frac{16}{Re'} \]

\[ Re' = \frac{VD\rho}{K} \left( \frac{4n}{1 + 3n} \right)^n \left( \frac{D}{8V} \right)^{n-1} \]

\[ V = \frac{Q}{\pi \cdot \left( \frac{D}{2} \right)^2} \]

\( V \): average velocity [m\( \cdot \)s\(^{-1}\)]
\( D \): pipe diameter [m]
\( L \): pipe length [m]
\( \rho_m \): sludge density [kg\( \cdot \)m\(^{-3}\)]
\( f \): friction factor [-]
\( Re' \): power law modified Reynolds number [-]
\( \Delta P \): total frictional pressure drop in the pipe [Pa]
Composition sludge

~ 80% moisture, except for section 8, pit 1 (~ 65%)
~ 35 % ash
Viscosity - comparison between pit sections

Section 8: not possible to perform analysis (no flow possible)
Viscosity - comparison between pit sections

**Pit 2**

**SHEAR THINNING BEHAVIOUR**

**NO EFFECT OF PIT SECTION**
Viscosity - comparison between pits

SAME BEHAVIOUR FOR DIFFERENT PITS
Viscoelastic properties

- 2000 Pa
- 5000 Pa

Diagram showing loss modulus (Pa) vs. frequency (1/s) with data points for Pit 1, Pit 2, and Pit 3.
Viscoelastic properties

![Graph showing viscoelastic properties with storage modulus (Pa) on the y-axis and frequency (1/s) on the x-axis. The graph includes data points for Pit 1, Pit 2, and Pit 3.]

\[1000 \text{ Pa}\]
\[10000 \text{ Pa}\]
Viscoelastic properties

Damping factor = Loss modulus / Storage modulus < 1

ELASTICITY > VISCOCITY
YIELD STRESS FOR FLOW
(~1 – 20 Pa)
Effect of moisture content of sludge

\[ \text{DECREASE OF MOISTURE CONTENT} \rightarrow \text{DECREASE OF VISCOCITY} \]
Effect of moisture content of sludge

Damping factor for different moisture contents < 1

DECREASE OF MOISTURE CONTENT
→ INCREASE DAMPING FACTOR
→ DECREASE OF YIELD STRESS (< 1 Pa)
Modelling

Power Law

\[ \tau = K \cdot \dot{\gamma}^n \]

\[ K = 1.9 \times 10^{51} \cdot MC^{-25.7} \]
\[ n = 3.2 \times 10^{-4} \cdot MC^{1.6} \]

Different from fresh faeces (Wolley et al. (2014))

Average deviation of 13 and 5% for \( K \) and \( n \), respectively

Maximum deviation of 37 and 9% for \( K \) and \( n \), respectively
Pumping requirements

INCREASE OF PUMPABILITY
⇒ INCREASE OF MOISTURE CONTENT
⇒ INCREASE OF PIPE DIAMETER
**Pumping requirements**

Omni-Ingestor criteria:
- Pit emptying rate = 3 l/s
- Pipe horizontal length = 100 m ; vertical length = 20 m

<table>
<thead>
<tr>
<th></th>
<th>Pipe diameter (m)</th>
<th>Moisture %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>75</td>
</tr>
<tr>
<td><strong>Hydraulic head (m)</strong></td>
<td>0.2</td>
<td>924-2537</td>
</tr>
<tr>
<td></td>
<td>0.3</td>
<td>298-714</td>
</tr>
<tr>
<td><strong>Pressure (bar)</strong></td>
<td>0.2</td>
<td>125-344</td>
</tr>
<tr>
<td></td>
<td>0.3</td>
<td>40-97</td>
</tr>
<tr>
<td><strong>Power (kW)</strong></td>
<td>0.2</td>
<td>38-104</td>
</tr>
<tr>
<td></td>
<td>0.3</td>
<td>12-29</td>
</tr>
</tbody>
</table>
**Plasticity and extrusion**

- **Moisture content**
  - 80%: Raw sludge → No pelletization possible
  - 77%: Sludge + Sawdust → Pelletization possible
  - 75%: Liquid limit
  - 70%: Plastic limit
  - 65%: Liquid limit
  - 60%: Plastic limit
  - Sludge LaDePa (pre-dried) → Pelletization possible

**PLASTICITY SUITABLE FOR EXTRUSION**
Conclusion about VIP faecal sludge

- Shear thinning fluid
- Elastic behaviour at rest → yield stress
- Similar rheological behaviour within the pit and among different latrines
- Low plasticity of sludge, so need to add a plasticiser (example: sawdust) or dewatering for extrusion
- Addition of water leading to the reduction of viscosity and yield stress → significant increase of pumpability

However: Addition of water not suitable depending on the upstream process (extrusion, drying)
Let’s evolve to a safer pit emptying!

Thanks a lot!

septiens@ukzn.ac.za